Ocean Data Assimilation for Coupled Models

Patricia A. Phoebus
Naval Research Laboratory
Monterey, CA 93943-5502
phone: (831) 656-4758 fax: (831) 656-4314 email: phoebus@nrlmry.navy.mil

James A. Cummings
Naval Research Laboratory
Stennis Space Center, MS 39529-5004
phone: (831) 656-5021 fax: (831) 656-4769 email: cummings@nrlmry.navy.mil

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LONG-TERM GOALS

The long-term goal of this and companion projects is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DOD's needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™)[1], and has already transitioned the atmospheric prediction system and ocean analysis components to operations.

OBJECTIVES

The objective of this particular project is to develop the globally-relocatable, three-dimensional multivariate ocean data analysis component of COAMPS to provide a capability that will 1) provide the best possible initial conditions for the mesoscale ocean forecast model and 2) provide accurate lower boundary conditions for the atmospheric forecast model. The emphasis is on the development of a complete ocean data assimilation capability, where oceanographic data from a variety of sources are assimilated into an ocean forecast model at regular intervals in a dynamically consistent fashion.

APPROACH

Plans for developing the next-generation ocean data assimilation system include leveraging the experience of both the atmospheric and oceanographic communities. We are expanding the univariate optimum interpolation (OI) approach to a fully multivariate, three-dimensional OI ocean data assimilation capability (3D MVOI), where adjustments to the ocean's mass field will be correlated with adjustments to the ocean's flow field, and a short-term model forecast will provide the analysis background field. Direct assimilation of non-conventional variables will be investigated. This capability will set the stage for utilizing even more sophisticated techniques in the future, such as three-dimensional and four-dimensional variational data assimilation. As we extend the analysis

[1] COAMPS™ is a trademark of the Naval Research Laboratory.

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The long-term goal of this and companion projects is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DOD???s needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS???)1, and has already transitioned the atmospheric prediction system and ocean analysis components to operations.

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capability to assimilate multiple variable types from a number of different sources, new quality control techniques are developed for those observations and the appropriate observation errors are evaluated. We will experiment with both loose to tightly coupled ocean/atmosphere systems, and all development will ultimately be tested within the structure of the entire coupled prediction system. All software developed is fully compatible with other existing and planned components of COAMPS, thereby providing a seamless depiction of the air/sea environment within a single package.

WORK COMPLETED

The COAMPS 3D MVOI has been incorporated as an integral part of the COAMPS software using a phased approach. Initially, a 2D analysis capability for SST and sea ice was developed and implemented to provide the lower boundary conditions on the COAMPS nested grids. This analysis was extended to a full 3D MVOI ocean analysis and integrated into COAMPS, and techniques were developed to assimilate synthetic profiles generated from MODAS (Modular Ocean Data Assimilation System) as part of the MVOI system, thereby bringing together these two technologies.

The 3D MVOI is now being used to initialize and cycle with the ocean forecast models in the both the regional COAMPS system and in the global coupled system based on the Navy Operational Global Atmospheric Prediction System (NOGAPS). In the regional system the ocean forecast model is the Navy Coastal Ocean Model (NCOM), and in the global system the ocean forecast component is the Parallel Ocean Program (POP). Prior to now, the Navy has not had a cycling data assimilation capability in the ocean and each new ocean analysis was an independent data-only analysis that did not use a forecast from a prediction model for background information.

In FY02, research efforts were focused on the investigation of an alternative method for the assimilation of satellite altimeter sea surface height observations. A direct assimilation method for altimetry was developed and tested in the 3D MVOI. Most ocean observations are remotely sensed and measure variables only at the surface. The lack of synoptic real-time data at depth places severe limitations on the ability of the data assimilative modeling system to resolve and maintain ocean fronts and eddies at correct locations. Subsurface properties in the ocean, therefore, must be inferred from surface-only observations. The most important observing system for this purpose is satellite altimtery, which measures changes in sea level from a long term mean. Changes in sea level are strongly correlated with changes in the depth of the thermocline in the ocean, and the ocean dynamics generating sea level changes are the energetic mesoscale eddies and meandering ocean fronts.

RESULTS

Sea level data from satellite altimeters is presently assimilated in the 3D MVOI via the generation of MODAS synthetic BTs within the analysis. The MODAS synthetics are computed from pre-defined statistical relationships between sea level anomalies and temperature at depth derived from historical profile observations. This approach has limitations in that the statistics depend on adequate sampling of the historical profile data, and the fact that the temperatures are constructed by computing anomalies from a static climatology. Repeated assimilation of MODAS synthetic BTs over time in a cycling data assimilation system tends to force the model forecast state to strongly reflect the underlying climatology, particularly at depth. Note also that the MODAS method only computes temperature profiles from sea level anomalies. Salinity is computed from the synthetic temperatures using a second set of historical profile regressions relating temperature and salinity on pressure levels.

An alternative approach to MODAS is the direct assimilation of observed sea level changes using a modified form of the dynamical method developed by Cooper and Haines (1996). In this approach, the model forecast density field is adjusted to correct for observed errors between the model forecast height field and the height field measured by the satellite altimeter. In the modifications to the Copper and Haines method implemented in the 3D MVOI, the depth range over which the density corrections are made is constrained to be between the mixed layer **(z_t)** and a level of no motion (z_b), defined appropriately for the model geographic domain. The adjustments are computed by integrating, where $\mathbf{\Delta p_s}$ is the surface pressure change measured by the difference between the model background

$$\Delta p_s + g\int_{z_b}^{z_t} \Delta\rho_z dz = \Delta p_b$$

and the satellite altimeter observation, $\Delta\rho_z$ is the change in density at level **z, g** is the gravitational constant, and $\mathbf{\Delta p_b}$ is the bottom pressure change. $\mathbf{\Delta p_b}$ is assumed to be zero at the level of no motion.

Output of the integration is in the form of innovations of temperature and salinity from the model forecast state that correct for the observed sea level model-data differences. The method does not introduce spurious water masses into the model by computing adjustments to the model temperature and salinity profiles simultaneously. Geopotential innovations are computed consistent with the temperature and salinity innovations, and velocity increments are computed from the geopotential increments using the multivariate correlations. The direct assimilation of altimeter sea level changes is model independent and does not require any pre-processing steps or statistical calculations. The method relies on model dynamics for *a priori* information and is therefore more adaptable to the particular model state at any one time. A potential disadvantage is that the method is based on local adjustment of the existing water column in the vertical and may not represent a realistic physical process. Further, the method cannot explicitly correct stratification in the model that is initially incorrect. The direct method assumes the observed sea level change is solely due to baroclinic processes. The method will be in error at high latitudes and elsewhere where the altimeter sea level anomaly data contain significant barotropic signals.

Validation of the direct method is being performed using the PALACE float (Profiling Autonomous Lagragian Circulation Explorers) real-time database. PALACE floats have been deployed throughout the world's oceans in recent years and provide very detailed vertical sampling of temperature and salinity from a wide range of geographic locations. In the validation analysis, sea level anomalies are computed for each cycle of a float from the previous cycle. The previous float profile is then modified by integration of the direct method using the observed change in sea level. The current float profile provides the verification data in the form of an observed temperature and salinity profile. Preliminary results show that the direct method has great skill in predicting observed changes in temperature and salinity from PALACE floats in the tropics and mid-latitude oceans. However, as expected, the method shows marginal skill at high latitudes or in cases where the mixed layer is very deep, such as the eastern North Atlantic in winter where mixed layer depths exceed 800 meters. A more complete description of the direct method validation study is underway. The direct method of assimilating altimeter sea level changes is now an integral part of the COAMPS 3D MVOI analysis. Cycling ocean data assimilation experiments are being performed to test the skill of the method with real altimeter data.

IMPACT/APPLICATIONS

Multivariate analysis of mass and velocity in the ocean is a new capability. In an ocean MVOI analysis, mass and velocity are consistent with simple linear dynamic constraints, and the constraints are built right into the algorithm. Enhanced ability to define the littoral battlespace environment through the optimal application of each critically important data point will provide Navy forces with a unique capability to exploit the environment to their tactical advantage.

TRANSITIONS

The 3D MVOI analysis is installed in the COAMPS developmental software configuration management system at NRL Monterey and is being transitioned via a complementary 6.4 project to Fleet Numerical Meteorology and Oceanography Center for implementation. The transition of the 3D MVOI analysis as an integral part of COAMPS is expected 1QFY03. All developmental and operational users of COAMPS routinely utilize the ocean data assimilation component. These users include the Navy operational centers, Navy Laboratories, the National Laboratories, and several universities.

RELATED PROJECTS

This project complements several ongoing ONR funded projects on Global Air-Ocean Coupling Development and Studies (N0001401WX20963) and Air/Ocean Model and Prediction System Development (N0001401WX20704) at NRL Monterey and at NRL Stennis.

SUMMARY

Steady progress has been made toward developing and implementing a complete 3D ocean multivariate optimal interpolation data assimilation system for use in coupled air/ocean modeling systems. Initial experiments indicate that a cycling data assimilation system in the ocean, comparable to that used in the atmosphere, is an appropriate and skillful solution for initializing the ocean forecast component of a coupled air/ocean prediction system. Optimal utilization of the relatively sparse oceanographic data in real-time requires sophisticated automated quality control procedures, which have been developed for all observation types. In addition, new techniques for assimilating non-conventional data such as altimeter sea surface height measurements are being actively investigated as an alternative to methods that rely heavily on climatological information.